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**Title:** LANL Experience Rolling Zr-Clad LEU-10Mo Foils for AFIP-7

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# LANL Experience Rolling Zr-Clad LEU-10Mo Foils for AFIP-7

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Materials Technology: Metallurgy Group (MST-6)  
Los Alamos National Laboratory

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(LANL Report LA-UR-13-xxxxx)

## Abstract

The cleaning, canning, rolling and final trimming of Low Enriched Uranium-10 wt. pct. Molybdenum (LEU-10Mo) foils for ATR (Advanced Test Reactor) fuel plates to be used in the AFIP-7 (ATR Full Size Plate In Center Flux Trap Position) experiments are summarized. Six Zr-clad foils were produced from two LEU-10Mo castings supplied to Los Alamos National Laboratory (LANL) by Y-12 National Security Complex. Details of cleaning and canning procedures are provided. Hot- and cold-rolling results are presented, including rolling schedules, images of foils in-process, metallography and local compositions of regions of interest, and details of final foil dimensions and process yield. This report was compiled from the slides for the presentation of the same name given by Duncan Hammon on May 12, 2011 at the AFIP-7 Lessons Learned meeting in Salt Lake City, UT, with Los Alamos National Laboratory document number LA-UR 11-02898.

## Background

Los Alamos National Laboratory was tasked with performing the co-rolling process on cast coupons produced at the Y-12 National Security Complex (Y-12). The coupons were sectioned and machined at Y-12. Coupons used for foils were nominally 5.75 x 3.75 x 0.130 inch thick, allowing three foils to be produced from each casting. Generally, the rolling process consists of the following steps:

- Clean U-10Mo coupon, pure zirconium foil, and steel rolling can material. Can material is A1011 CS Type B hot-rolled steel, 0.130 inch thick. Scale was initially removed by bead blasting with glass beads. Zirconium foil was 0.0095 inch thick. Steel components cleaned in Blue Gold bath. Zr foils cleaned in Blue Gold followed by nitric-HF acid. LEU-10Mo cleaned in Blue Gold followed by nitric acid.
- Assemble rolling can with Zr on either side of U-10Mo. The rolling can consists of 3 layers of steel plate, one of which has a U-10Mo coupon-sized hole cut in the center (“picture frame”). Neolube parting agent is applied by brush between the Zr and the steel can, and the Zr is tack welded to the outer steel pieces.

- Weld rolling can to seal contents. Welding is performed using autogenous Gas Tungsten Arc Welding (GTAW) in an argon (<20 ppm O<sub>2</sub>) atmosphere.
- Heat rolling can in air furnace set to 680°C for ½ hour. Desired rolling temperature is 650°C.
- Roll can from 0.410 inch thickness in approximately 10% reduction steps to final thickness of approximately 0.055 inches. Reheat for 5 minutes between each pass. Total of 15 or 16 passes.
- Anneal rolled can for ½ hour in 680°C air furnace.
- Decan using foot-shear.
- Trim foils using foot-shear as needed. Clean foils with ethanol to remove parting agent.
- Cold-roll from starting thicknesses of approximately 0.020-0.022 inch to final thicknesses of approximately 0.015-0.016 inch. Typically performed in 8-10 passes.
- Trim foils using foot-shear as needed.

In total, six coupons were processed using this method: PVNF, PVME, PVMF, R1X4, R1X6, and R1X9. Coupons were machined from two castings, with the three “P” coupons coming from one and the three “R” castings coming from the other. Each casting was produced at Y-12 in a “book” mold with approximate dimensions of 9.75 x 8.0 x 0.220 inches, not including the hot-top. PVME, PVMF, and R1X6 were used in the AFIP-7 fuel element for reactor testing, in addition to foil R9HT, which was processed at Y-12.

The attached slides give details on AFIP-7 foil production at LANL, including images of foils at each stage of processing, metallographic images of locations of interest, and details of rolling schedule and material utilization.

# LANL EXPERIENCE ROLLING Zr-CLAD LEU10Mo FOILS FOR AFIP-7

May 12, 2011

Duncan Hammon, Kester Clarke  
And others

Can Material:

A1011 CS Type B, hot-rolled steel, 0.130" thick, 0.05C,

Scale removed by bead blasting with glass beads.

Zirconium foil, 0.0095" thick

Cleaning:

Steel components cleaned in Blue Gold.

Zr foils cleaned in Blue Gold followed by nitric-HF acid.

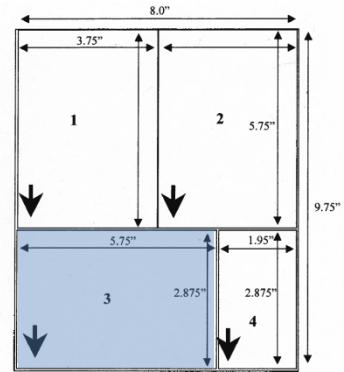
LEU cleaned in Blue Gold followed by nitric acid.

Neolube brushed onto steel for parting agent.

Welding:

Welded in argon atmosphere, <20 ppm O<sub>2</sub>

Autogenous GTA weld



# LEU-10 Mo Sample PVNF

# Hot Rolled Can



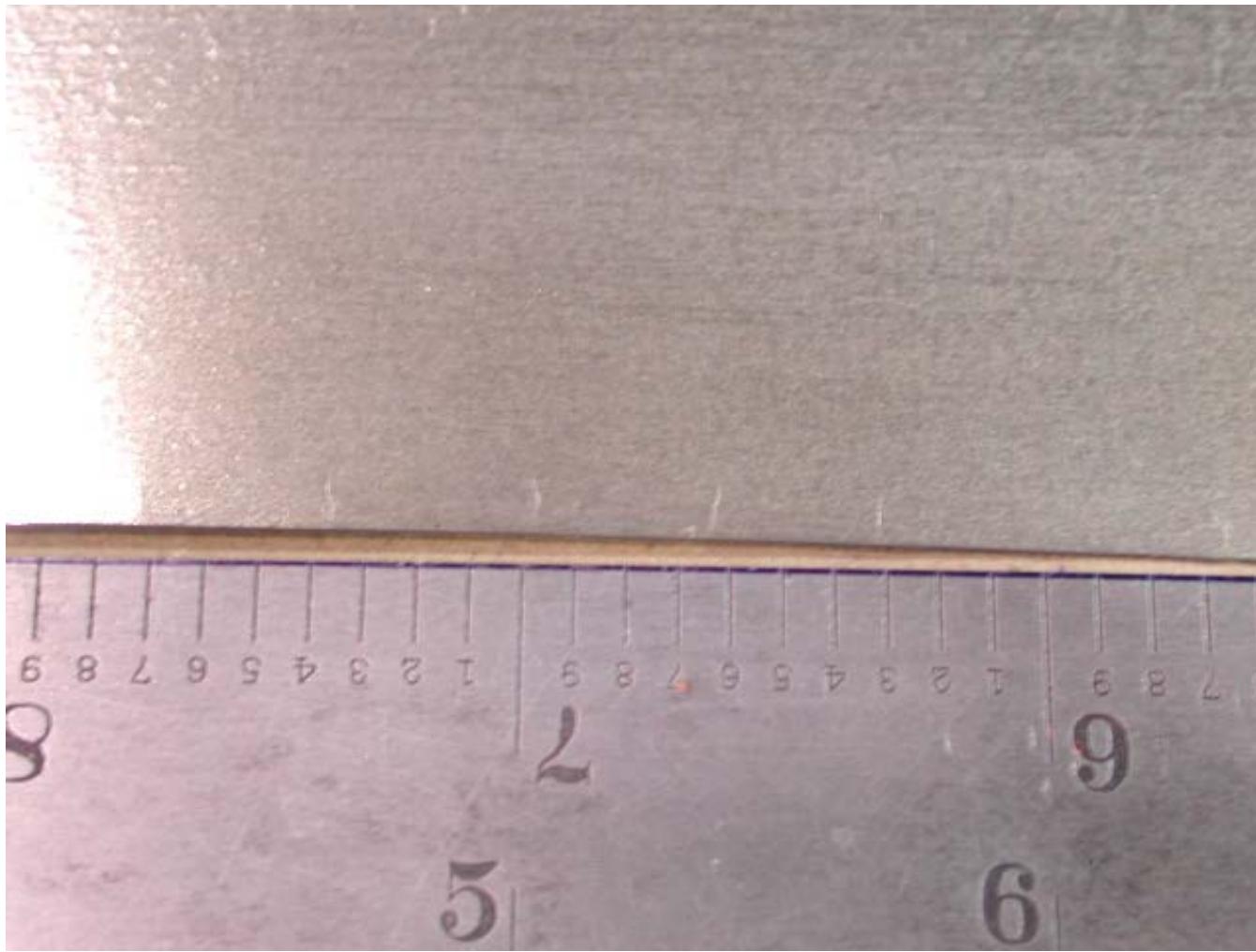
# Hot Rolled Foil



# Cold Rolled Foil



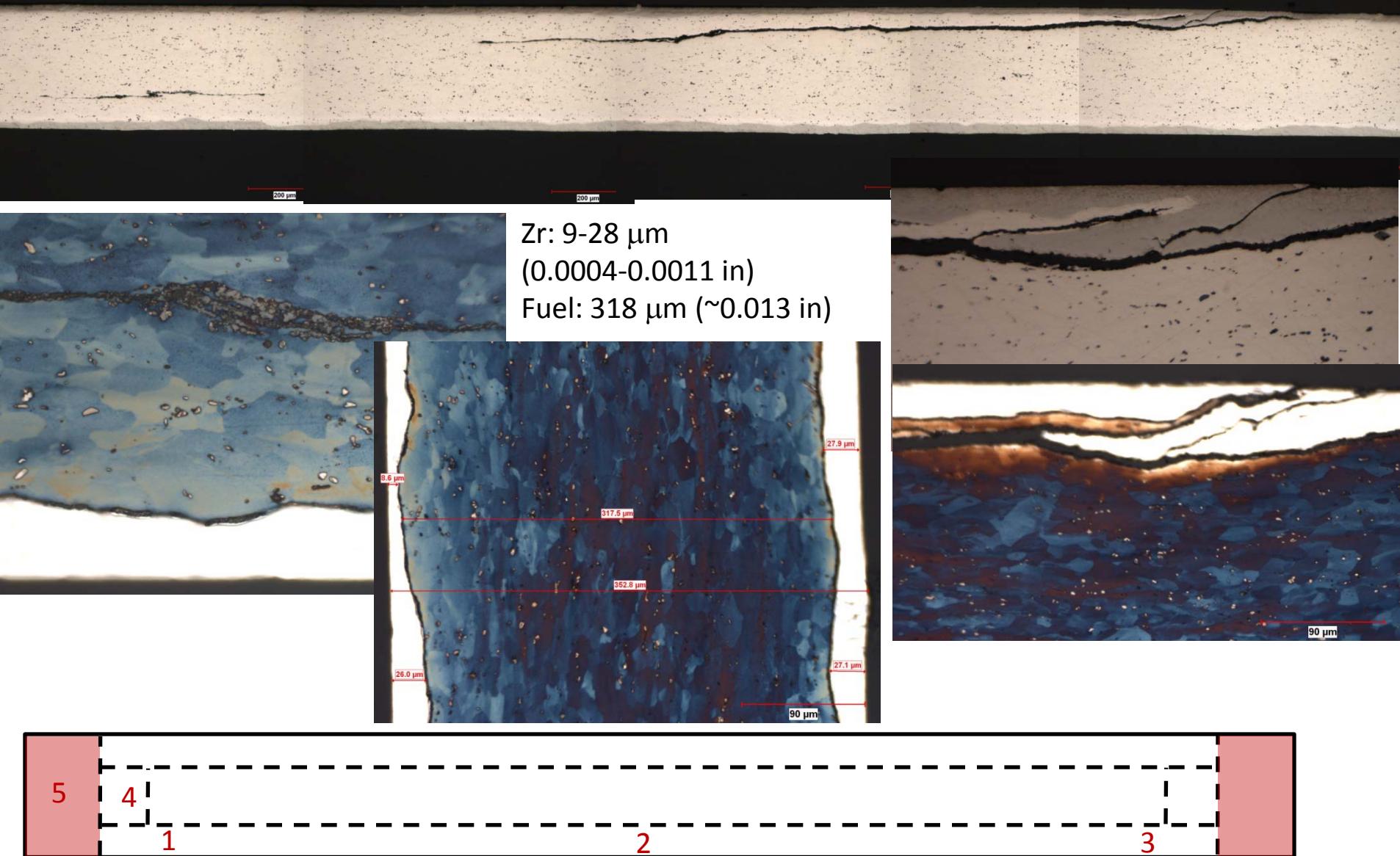
# Edge Cracks

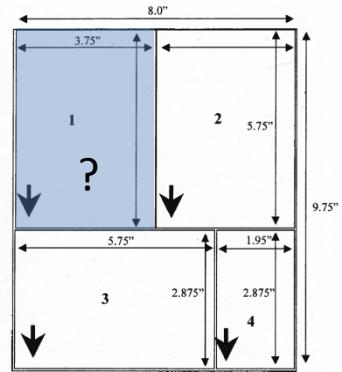


# Trimmed Foil



# LOM Results (12420): Sample 5, PN:3G60-CN-PVNF -LEU, Cold rolled, Transverse



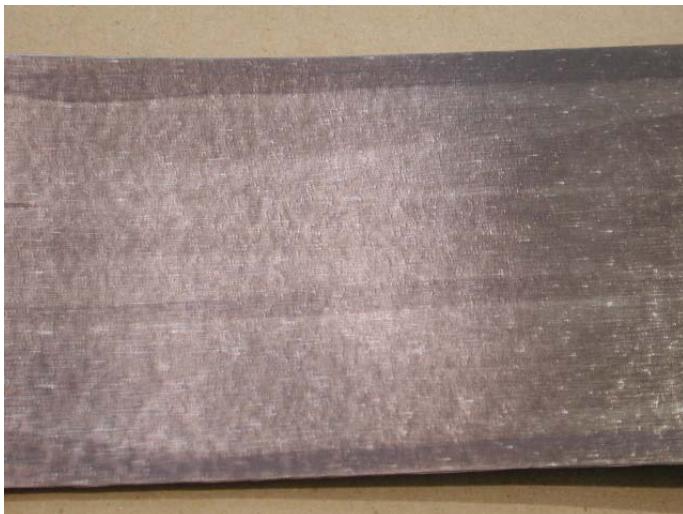


# LEU-10 Mo

## Sample PVME

# LOM Results (12431): PN:3G60-CK-PVME -LEU

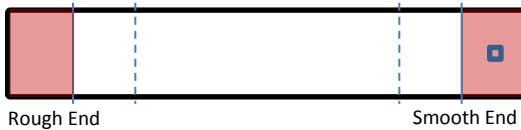
Rough End



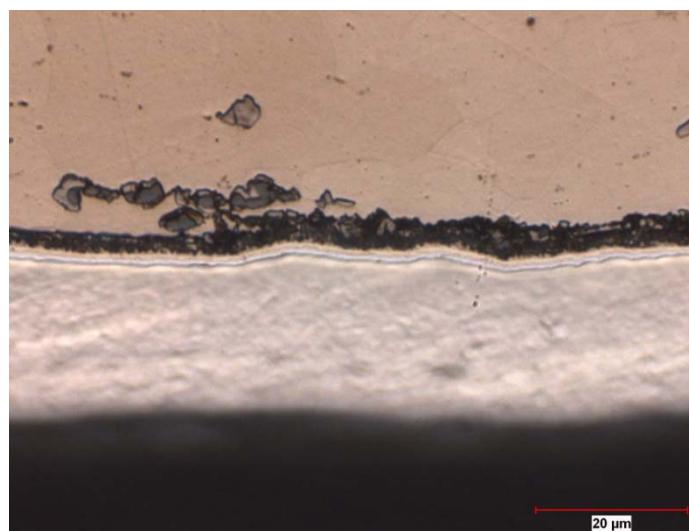
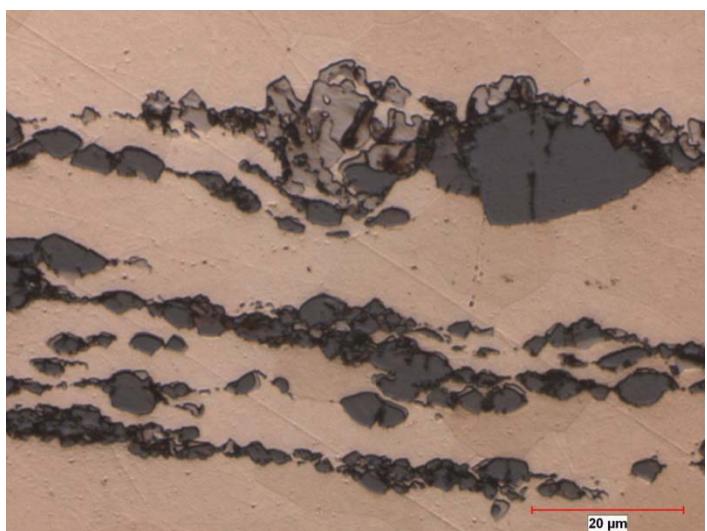
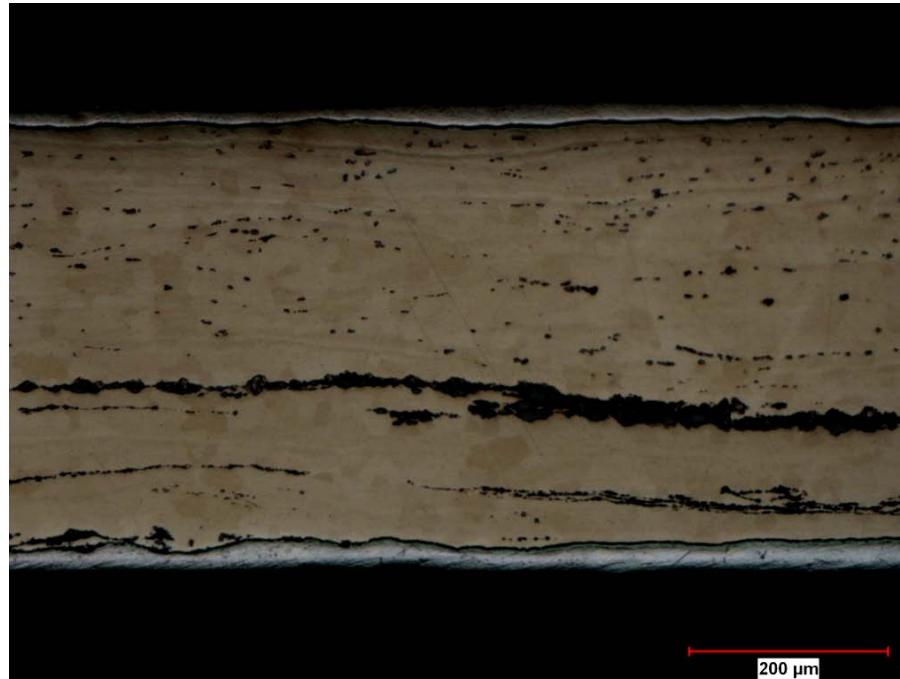
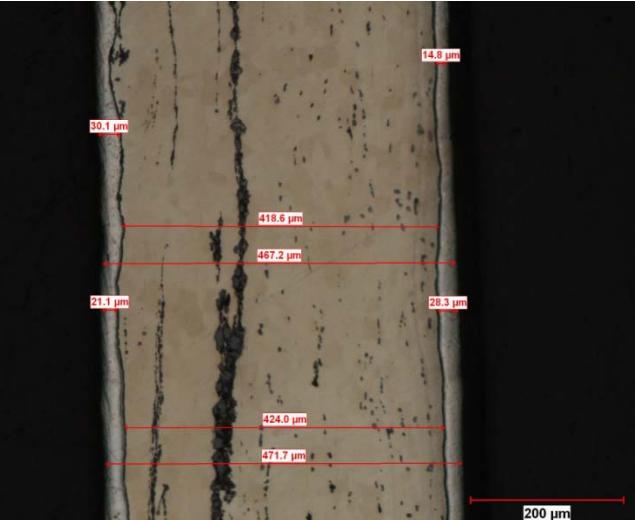
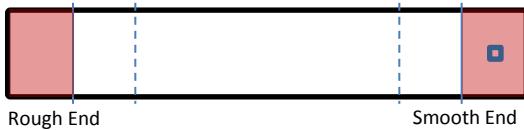
Smooth End



# LOM Results (12431): Sample 5, PN:3G60-CK-PVME -LEU, Hot-rolled, visible defect, smooth end



# LOM Results (12431): Sample 5, PN:3G60-CK-PVME -LEU, Hot-rolled, visible defect, smooth end

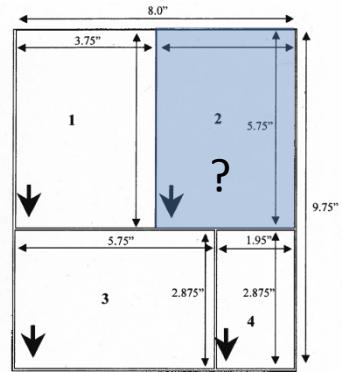


Zr: 15-30 µm  
0.0008-0.0015 in

Fuel: 420 µm  
~0.016 in

Total: 470 µm  
~ 0.019 in

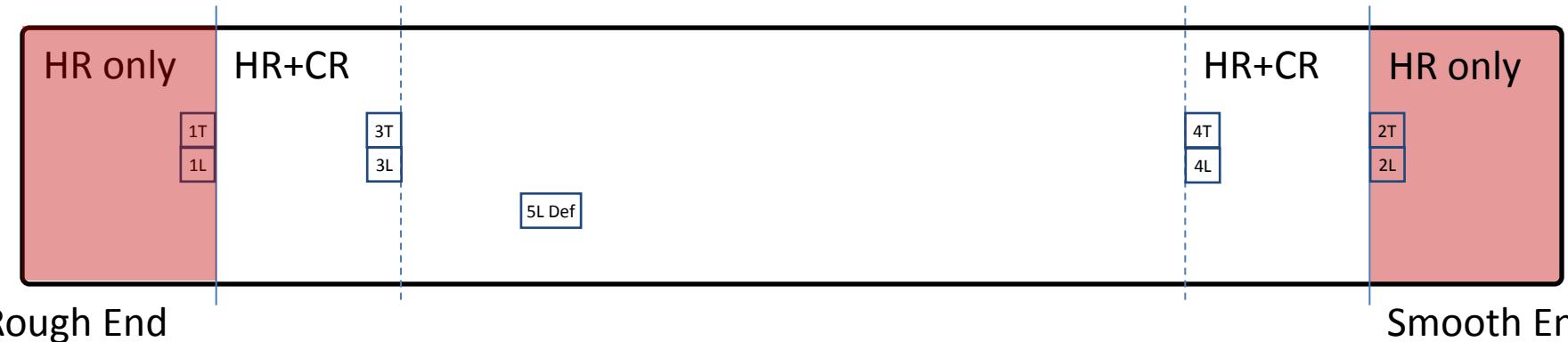
Longitudinal



# LEU-10 Mo

## Sample PVMF

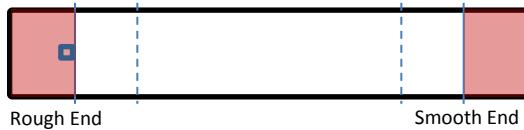
# LOM Results (12432): PN:3G60-CK-PVMF -LEU



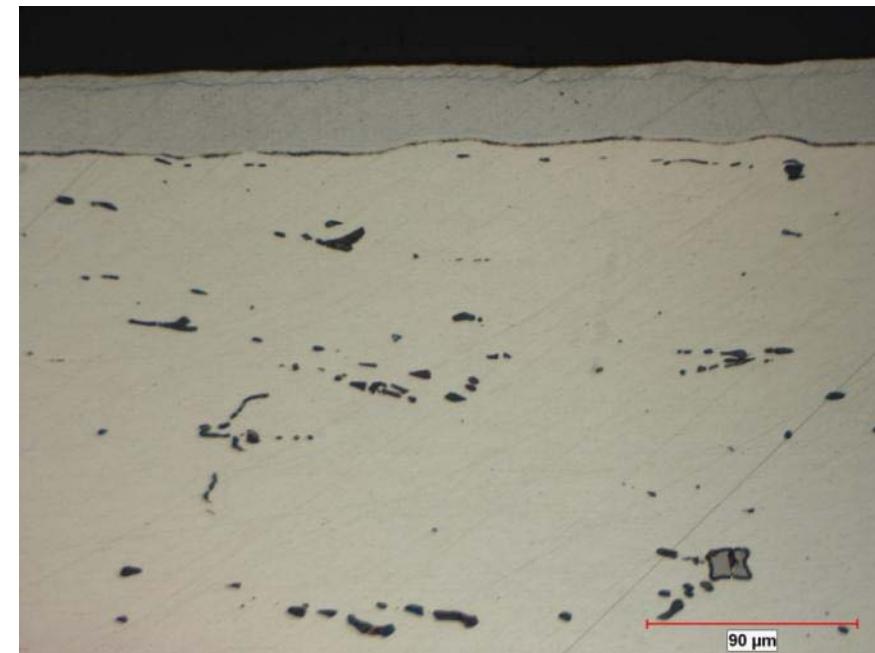
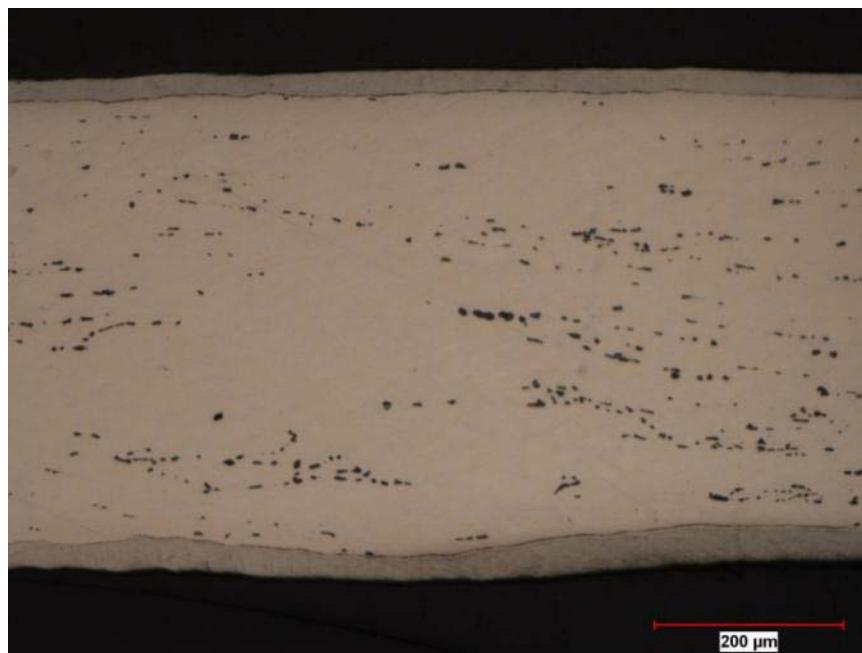
# Results (12432): PN:3G60-CK-PVMF -LEU, Hot-rolled



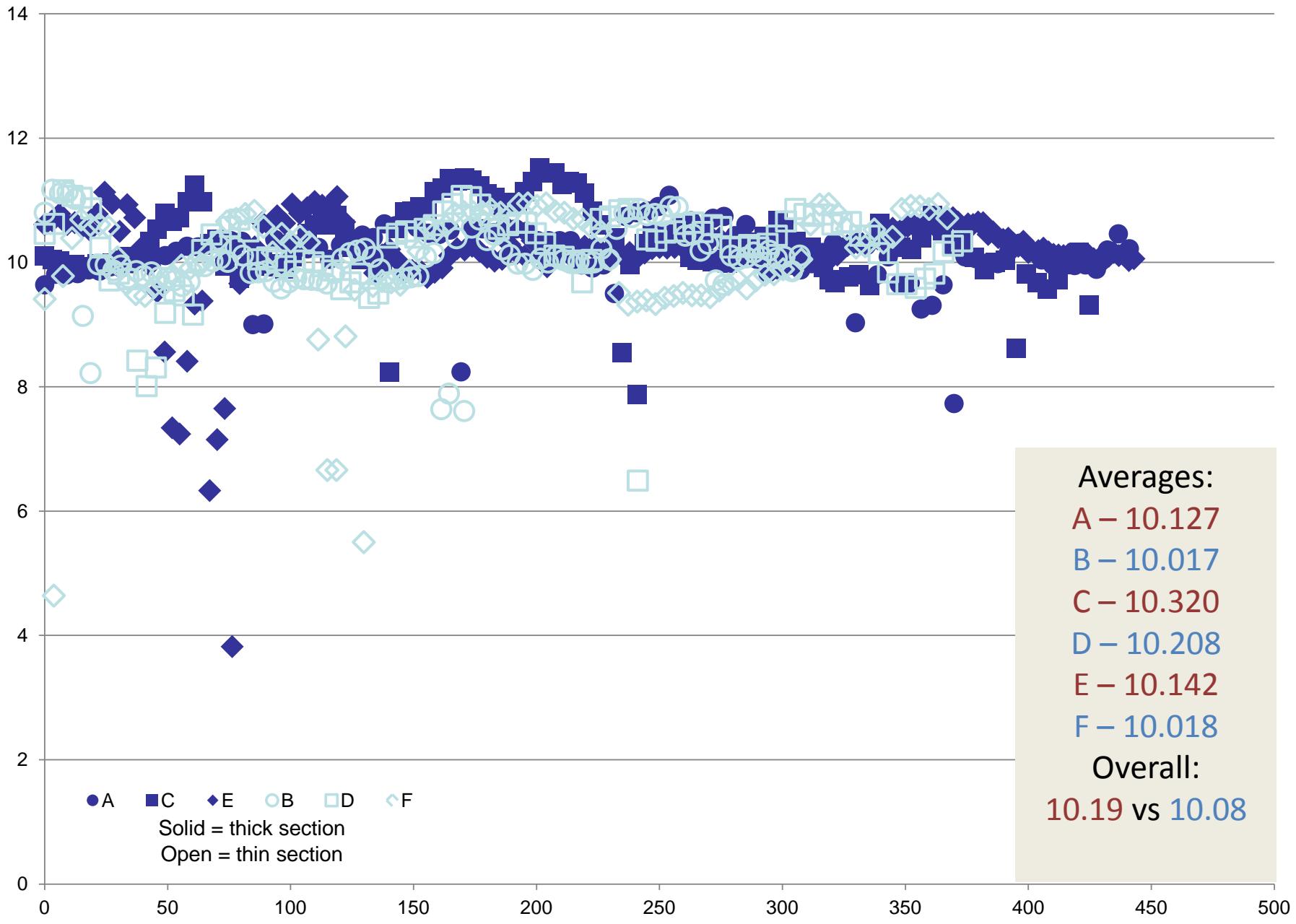
# Results (12432): PN:3G60-CK-PVMF -LEU, Hot-rolled, ROUGH END, Sample 1L



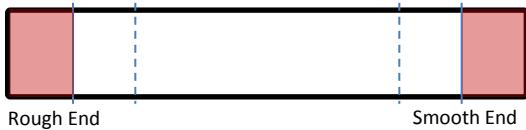
Inclusion fraction does not appear to directly correlate with thickness variation.



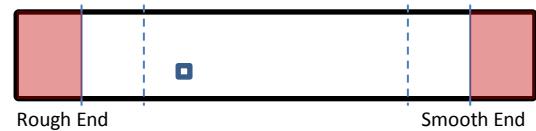
# EPMA Molybdenum (wt. pct.) scans for locations A-F, overlayed



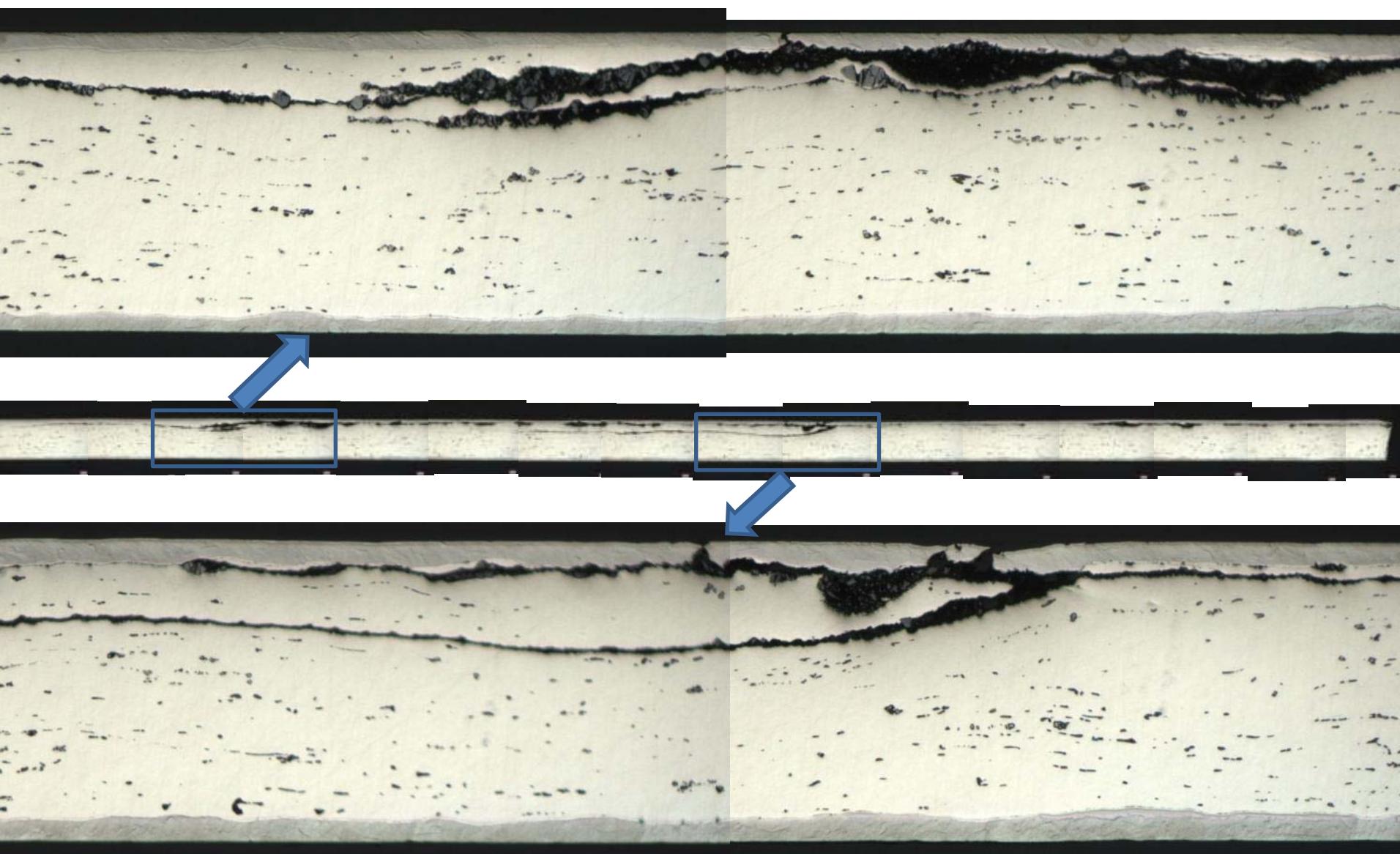
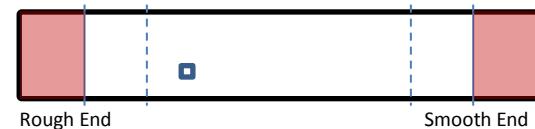
# Results: PN:3G60-CK-PVMF -LEU, Cold-rolled



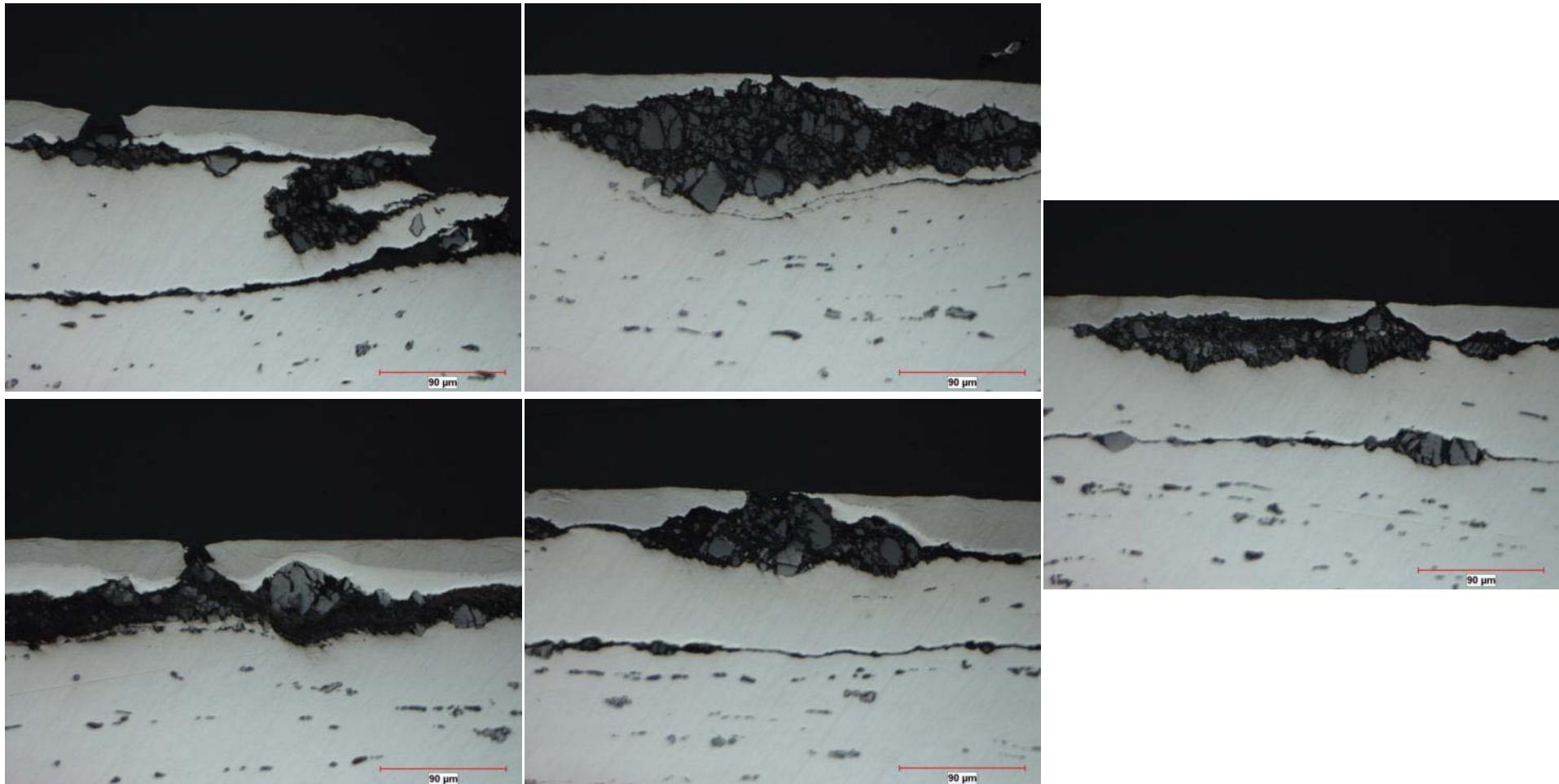
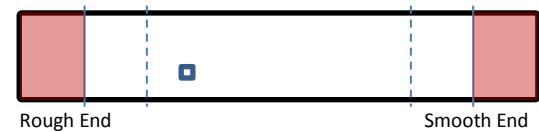
# Results (12432): PN:3G60-CK-PVMF -LEU, Cold-rolled, Sample 5



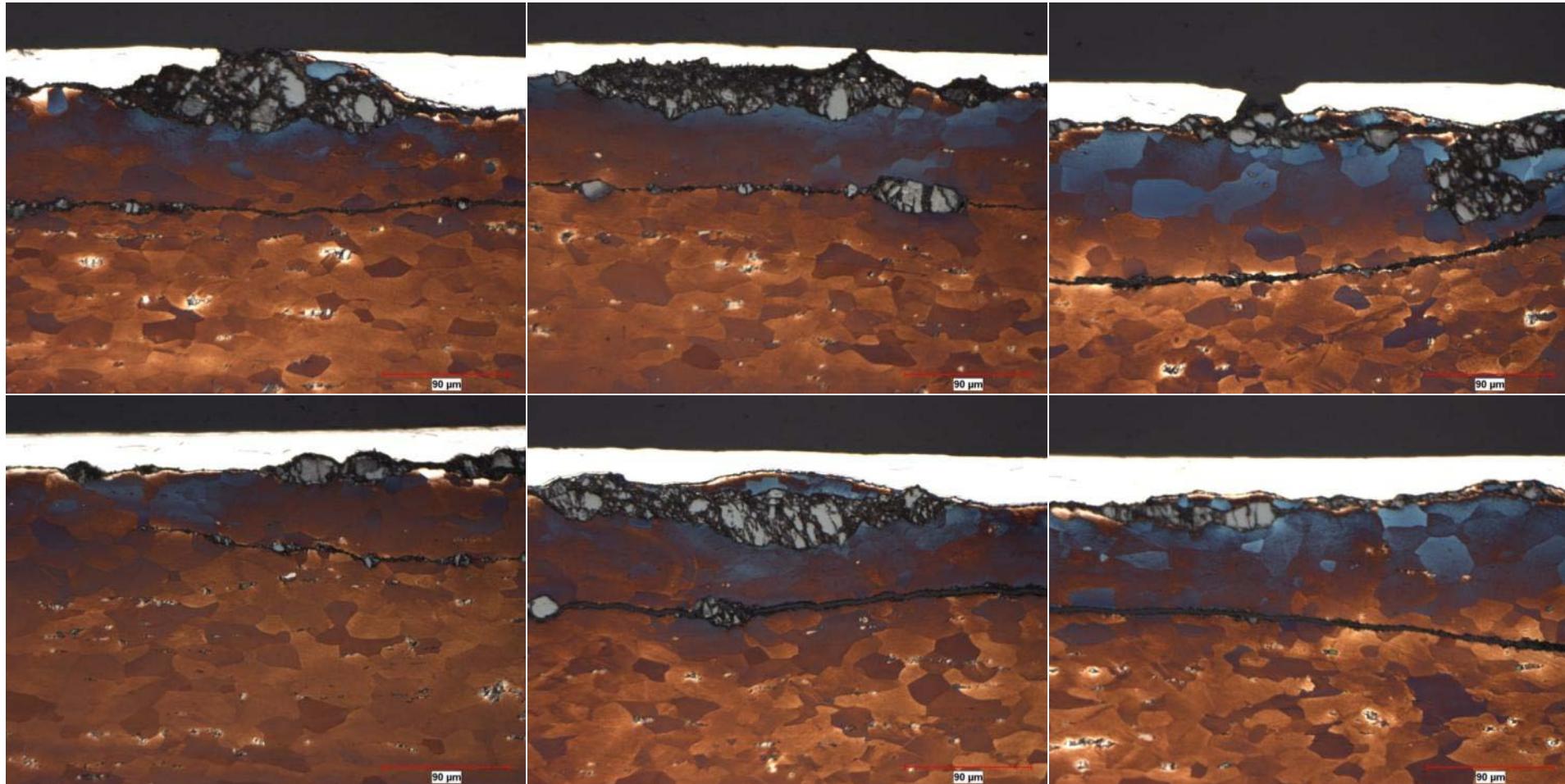
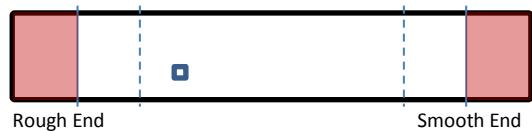
# Results (12432): PN:3G60-CK-PVMF -LEU, Cold-rolled, Sample 5, approx. 0.5 in



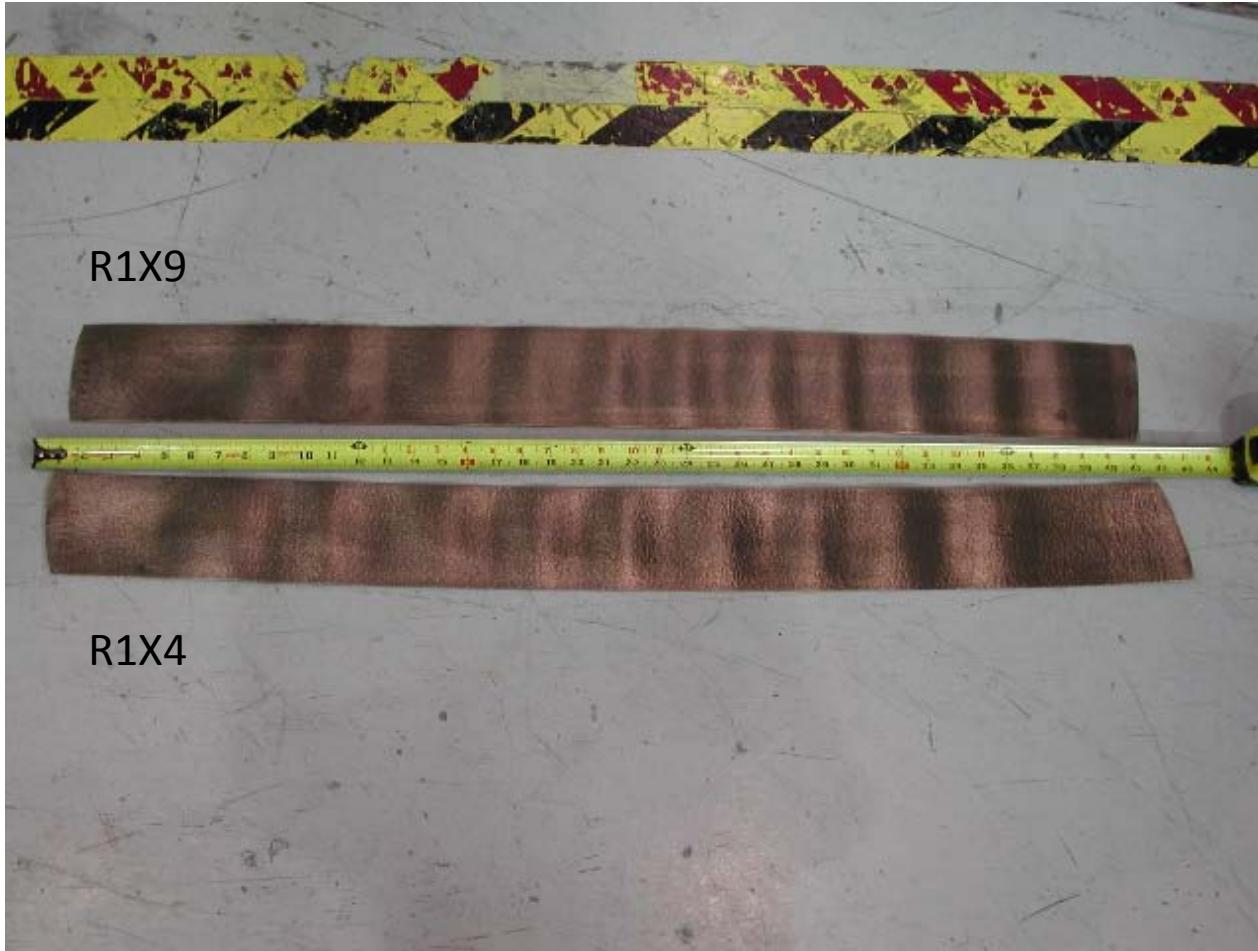
# Results (12432): PN:3G60-CK-PVMF -LEU, Cold-rolled, Sample 5



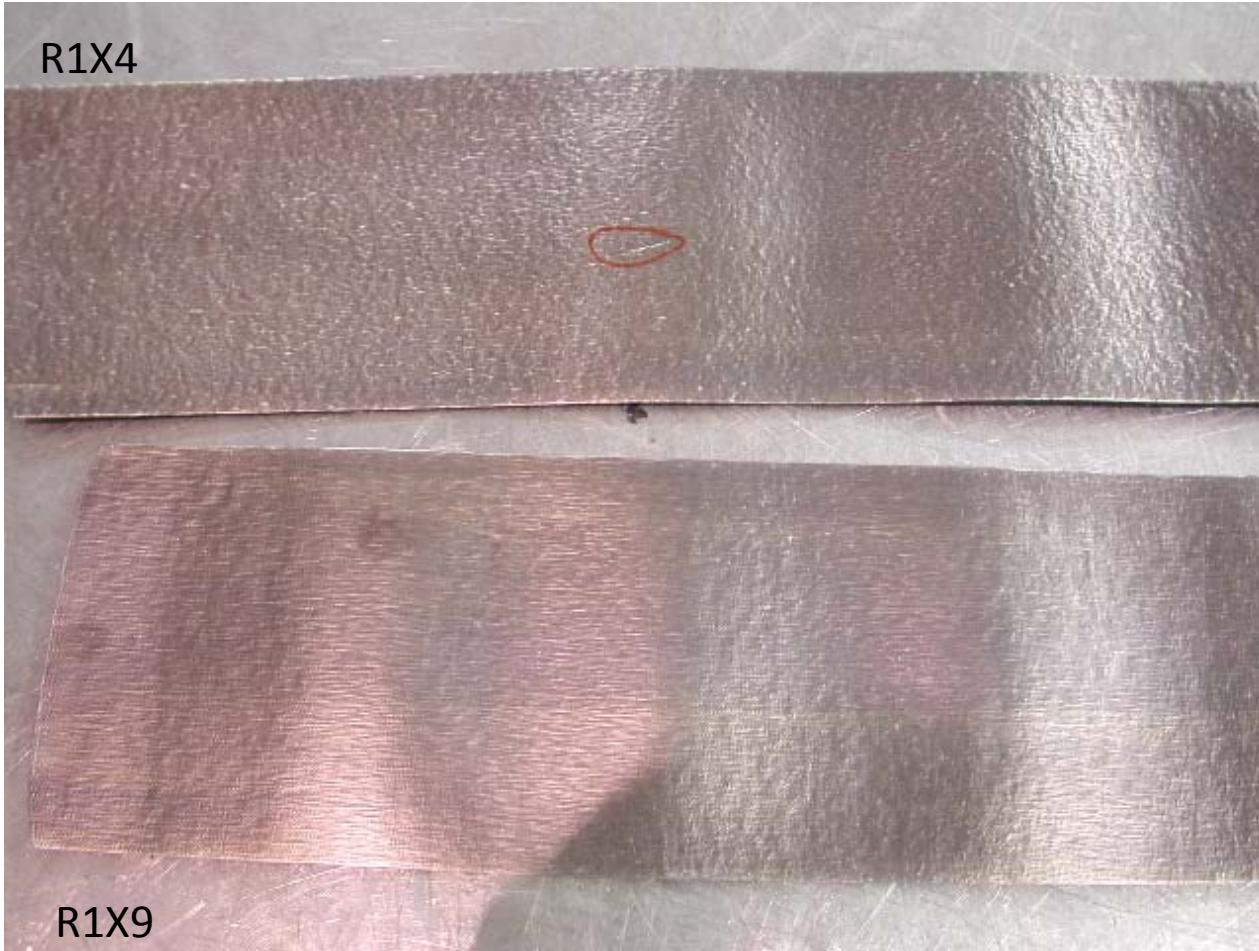
# Results (12432): PN:3G60-CK-PVMF -LEU, Cold-rolled, Sample 5



# R1X4, R1X9 Hot Rolled



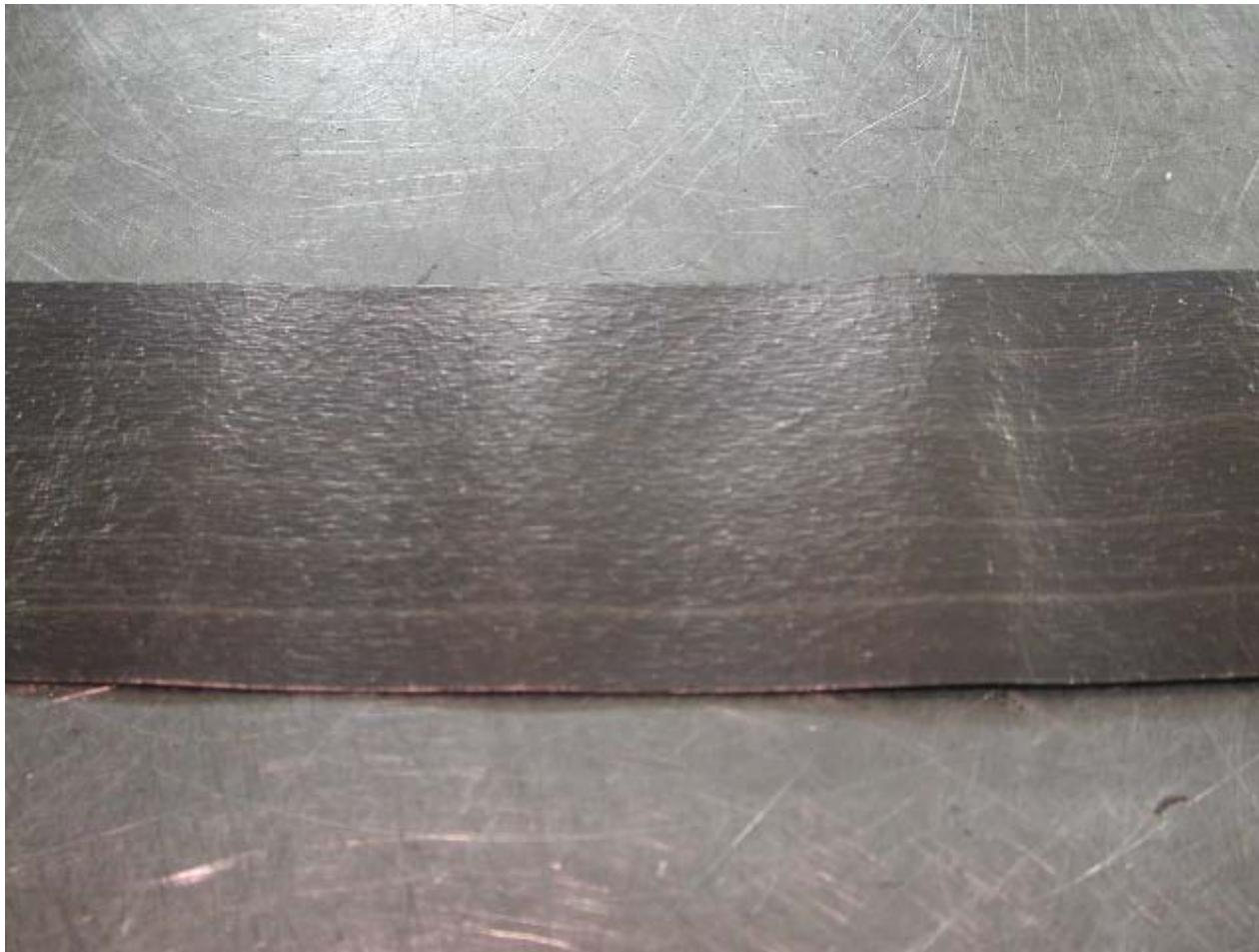
# R1X4, R1X9 Hot Rolled



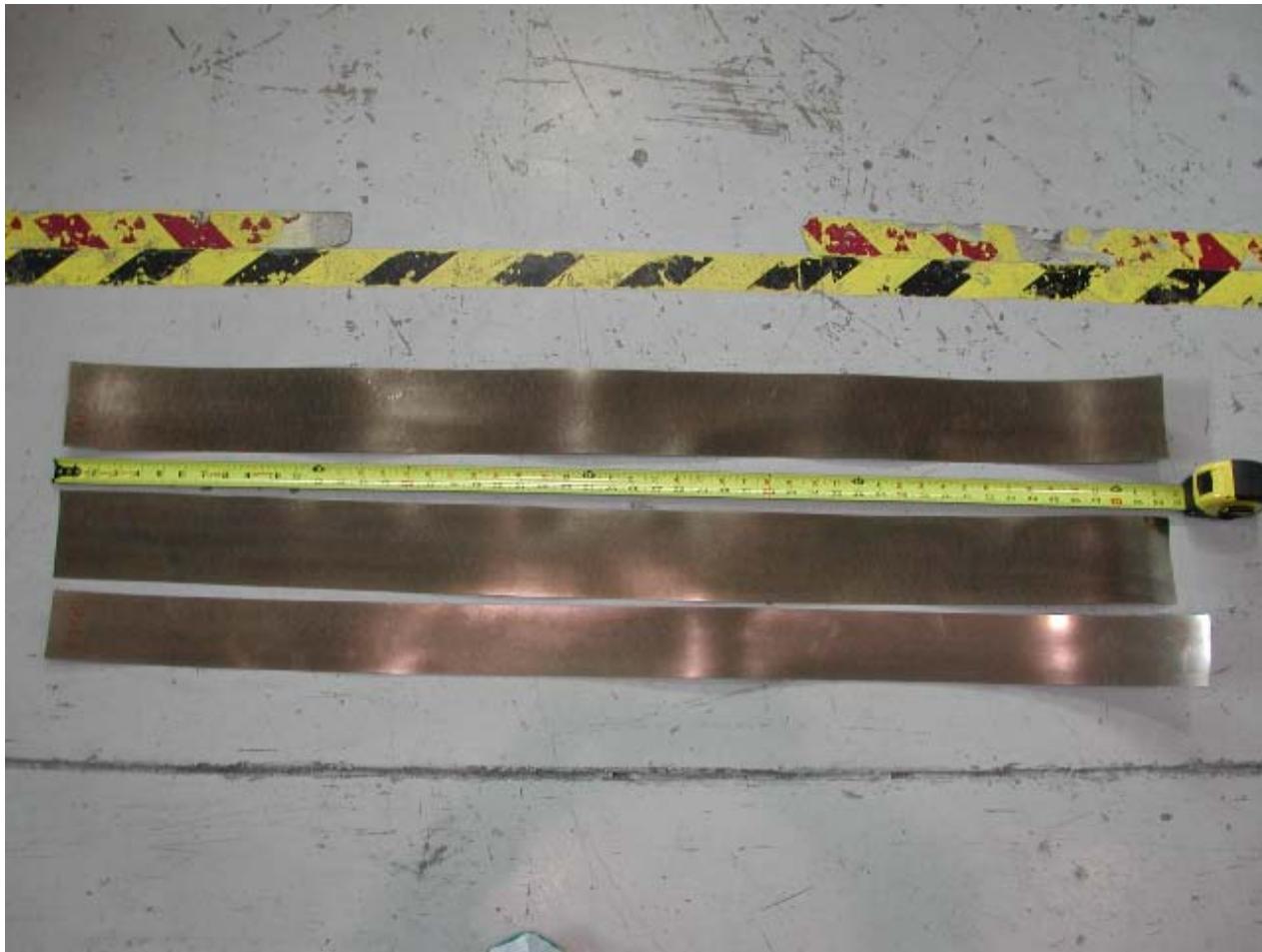
# R1X6 Hot Rolled



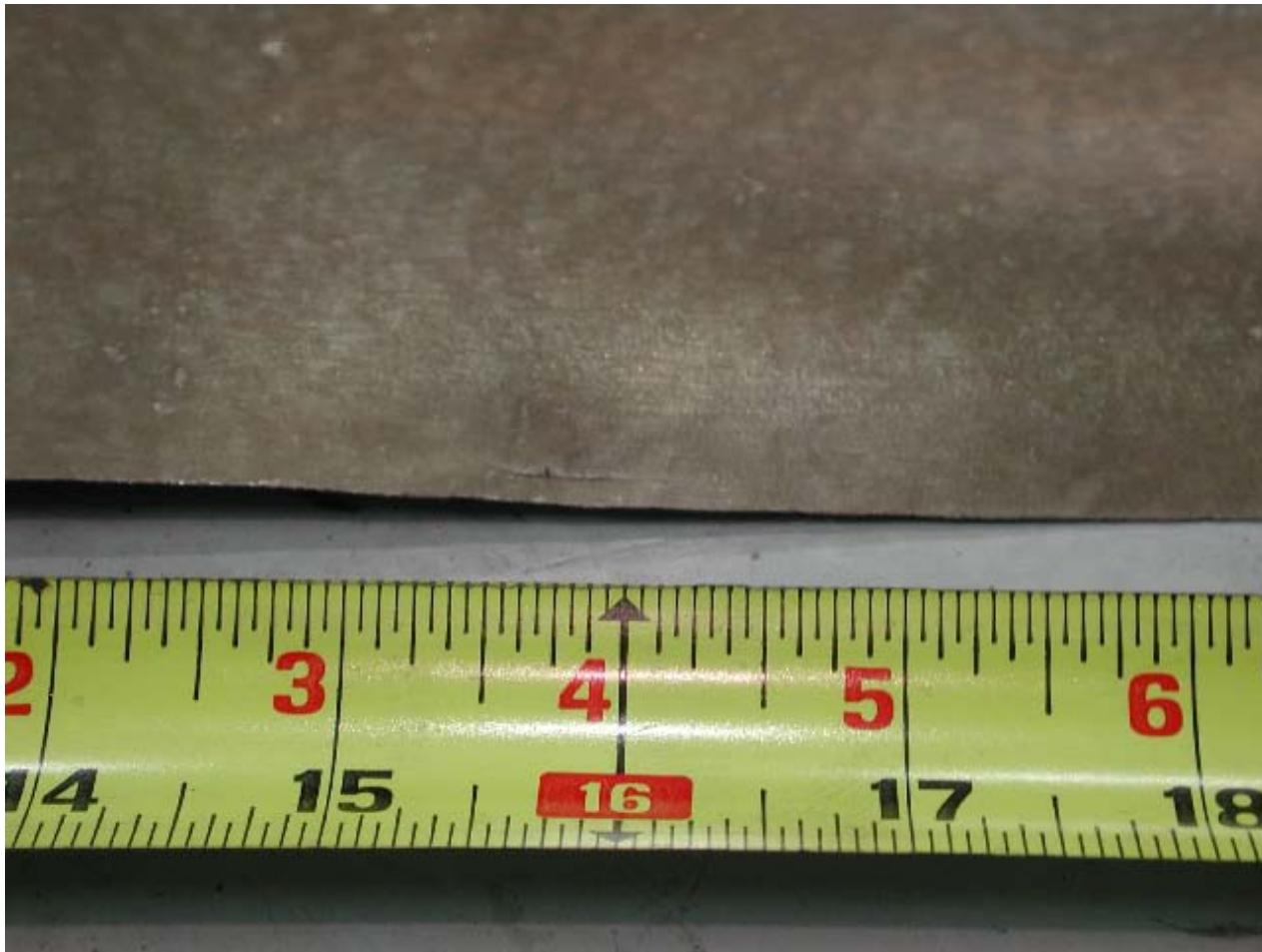
# R1X6 Hot Rolled



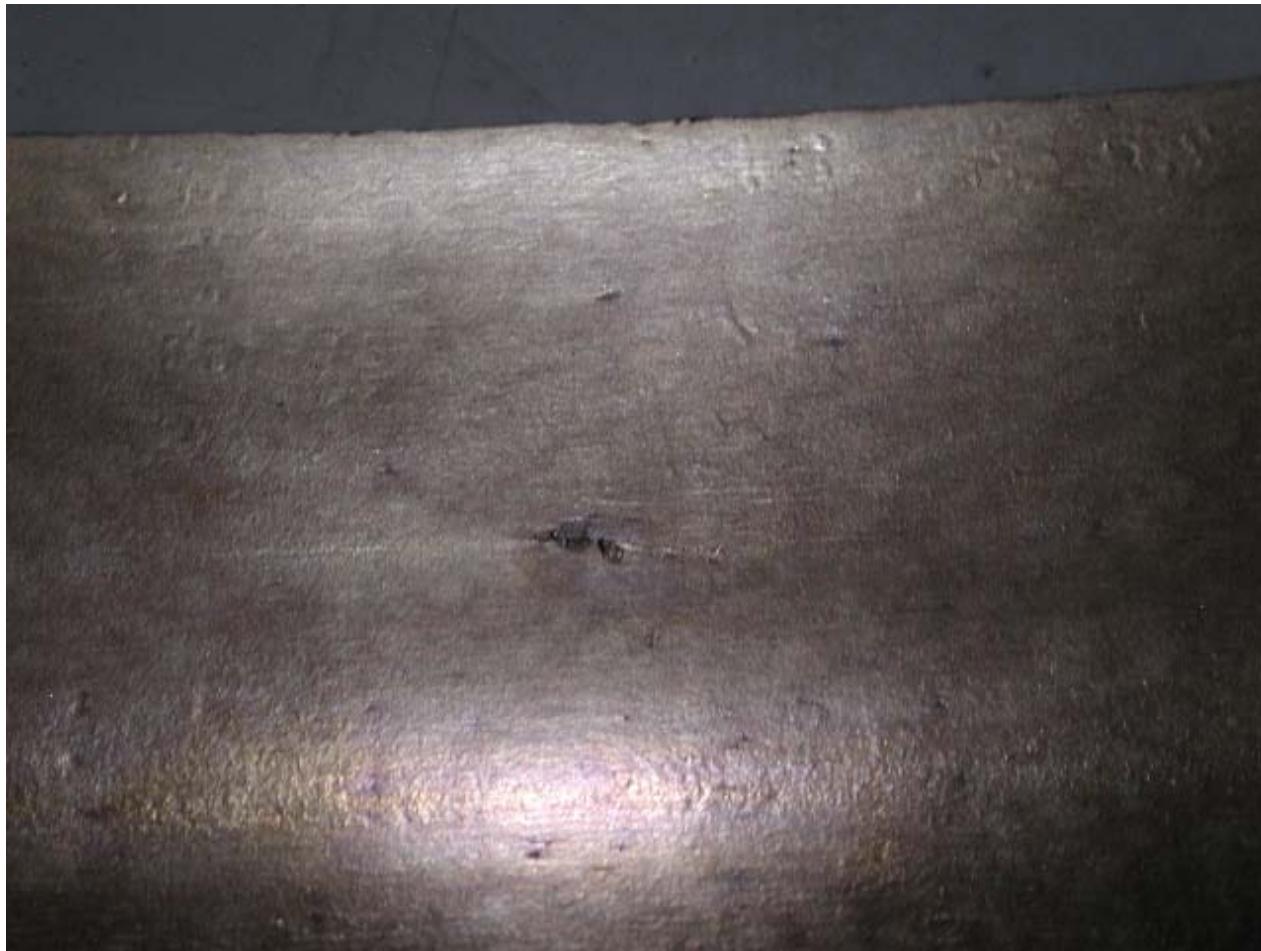
# Cold-Rolled Foils



# R1X4 Cold Rolled



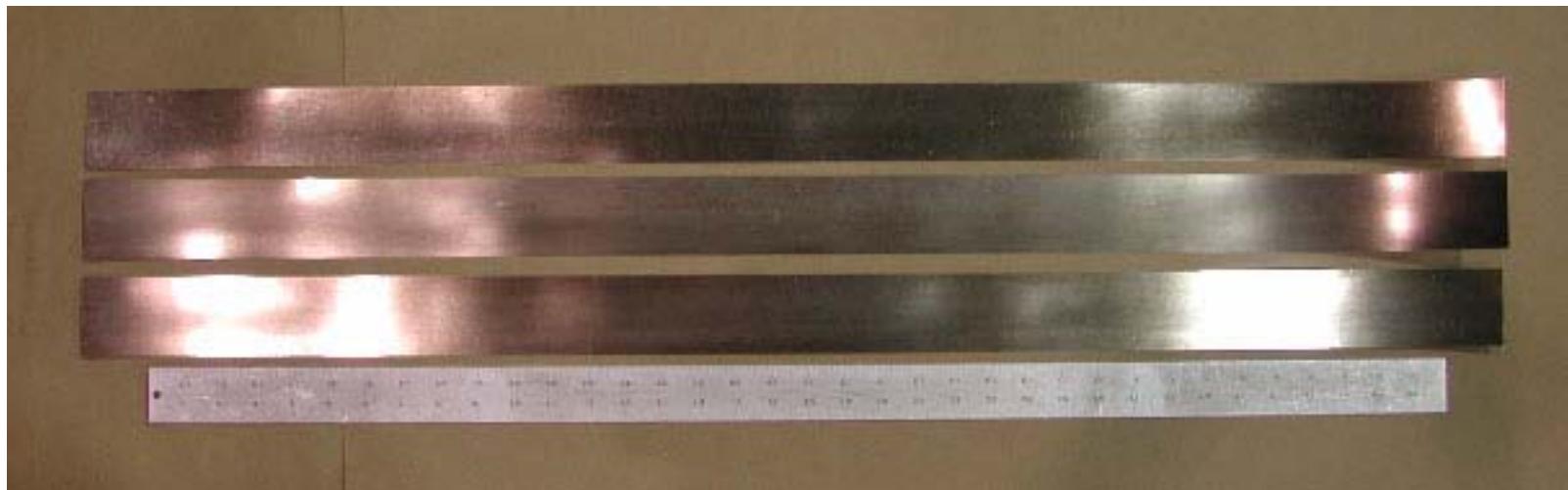
# R1X4 Cold Rolled



# R1X9 Cold Rolled



# Trimmed Foils



R1X4

R1X6

R1X9

# Trimmed Foils



R1X4

R1X6

R1X9

# 3G60-CK-R1X4

Position **	Width	Thick Edge 1	Thick Edge 2
0	2.160	0.0160	0.0162
9	2.168	0.0159	0.0159
18	2.163	0.0160	0.0157
27	2.168	0.0159	0.0158
36	2.158	0.0160	0.0161
Average	2.163	0.0159	

# 3G60-CN-R1X6

Position **	Width	Thick Edge 1	Thick Edge 2
0	2.165	0.0149	0.0150
9	2.168	0.0149	0.0150
18	2.165	0.0150	0.0150
27	2.169	0.0148	0.0150
36	2.162	0.0149	0.0150
Average	2.166	0.0149	

# 3G60-CK-R1X9

Position **	Width	Thick Edge 1	Thick Edge 2
0	2.164	0.0154	0.0157
9	2.168	0.0155	0.0155
18	2.164	0.0155	0.0156
27	2.168	0.0154	0.0155
36	2.160	0.0155	0.0157
Average	2.165	0.0155	

# Material Utilization

Billet ID	Billet Weight	Clad Foil	Trimmed Foil	Scrap Percent
R1X4	787.4	829.1	344.0	58.5
R1X6	601.2	632.2	327.2	48.2
R1X9	792.1	834.6	336.8	59.6

LEU10Mo

3G60-CK-PVME

Hot Rolling in a Steel Can

Bliss Mill

5/18/2010

Initial Thickness      0.413  
 Initial Width      4.92

Initial Length      6.93

Pass No.	Time	Direction	Mill Setting	Thickness Before	Measured Thickness After	Reduction	In Furnace
	3:08						
1	3:38	F	0.380	0.413	0.366	0.047	
2	3:43	R	0.340	0.366	0.329	0.037	
3	3:48	F	0.300	0.329	0.291	0.038	
4	3:53	R	0.260	0.291	0.253	0.038	
5	3:58	F	0.230	0.253	0.220	0.033	
6	4:03	R	0.200	0.220	0.192	0.028	
7	4:08	F	0.170	0.192	0.167	0.025	
8	4:13	R	0.145	0.167	0.147	0.020	
9	4:18	F	0.120	0.147	0.122	0.025	
10	4:23	R	0.100	0.122	0.101	0.021	
11	4:28	F	0.090	0.101	0.087	0.014	
12	4:33	R	0.080	0.087	0.078	0.009	
13	4:38	F	0.070	0.078	0.068	0.010	
14	4:43	R	0.065	0.068	0.062	0.006	
15	4:48	F	0.065	0.062	0.058	0.004	
16	4:53	R	0.065	0.058	0.054	0.004	

58 x (5.130/5.160) x (.046/.0465) oxide removed

Air furnace set at 680 C

Anneal 30 minutes after rolling. Swap ends at 15 minutes.

Final can dimensions	58.000	5.160	0.0465 oxide removed
		5.130	0.046 oxide removed
		5.153	0.0465 oxide removed

Foil dimensions	46.5	3.920	0.02205 rough end
		3.943	0.0204
		3.932	0.01885 smooth end

LEU10Mo	3G60-CK-						
Finish Rolling	PVME						
		Loewy Mill					19-May-10
Initial							
Thickness	0.019						
Initial							
Width	3.93						
Initial							
Length	37						
Pass No.	Number of passes	Direction	Mill Setting	Thickness Before	Calculated Thickness After	Length	Measured Thickness After
1	3	R	0.0210		0.0187	37.50	
2	3	R	0.0185	0.0187	0.0185	38.00	
3	3	R	0.0170	0.0185	0.0182	38.63	
4	3	R	0.0160	0.0182	0.0179	39.25	0.0170
5	3	R	0.0150	0.0179	0.0176	40.00	
6	3	R	0.0140	0.0176	0.0172	40.88	
7	4	R	0.0125	0.0172	0.0166	42.38	0.0157
8	4	R	0.0115	0.0166	0.0160	44.00	0.0150

R: Rough texture end first

3G60-CK-PVME

Final Foil Dimensions

Duncan  
Hammon

25-May-10

Position	Width	Thick Edge 1	Thick Edge 2	Thick Center
1	2.164	0.0156	0.0154	0.0154
8	2.166	0.0153	0.0155	
16	2.165	0.0155	0.0154	
24	2.170	0.0155	0.0154	0.0154
32	2.170	0.0150	0.0153	
39.5	2.163	0.0152	0.0153	0.0153
Average	2.166	0.0153		

Length            39.500

Foil Wt.        332.6

Scrap Wt.       515.8

Gross  
Density        15.4044

LEU10Mo  
 Hot Rolling in a Steel Can  
 3G60-CK-PVMF  
 Bliss Mill  
 5/17/2010  
 Initial Thickness 0.41  
 Initial Width 4.9  
 Initial Length 6.925

Pass No.	Time	Direction	Mill Setting	Thickness Before	Measured Thickness After	Reduction
1	10:40	F	0.380	0.410	0.366	0.044
2	10:45	R	0.340	0.366	0.325	0.041
3	10:50	F	0.300	0.325	0.284	0.041
4	10:55	R	0.260	0.284	0.250	0.034
5	11:00	F	0.230	0.250	0.218	0.032
6	11:05	R	0.200	0.218	0.191	0.027
7	11:10	F	0.170	0.191	0.162	0.029
8	11:15	R	0.145	0.162	0.138	0.024
9	11:20	F	0.120	0.138	0.118	0.020
10	11:25	R	0.100	0.118	0.099	0.019
11	11:30	F	0.090	0.099	0.086	0.013
12	11:35	R	0.080	0.086	0.076	0.010
13	11:40	F	0.070	0.076	0.064	0.012
14	11:45	R	0.065	0.064	0.057	0.007
15	11:50	F	0.065	0.057	0.051	0.006

$$53.5 \times (5.103/5.138) \times 0.050$$

Air furnace set at 680 C.

Anneal 30 minutes after rolling. Swap ends at 15 minutes.

5.126

Final can dimensions	53.500	5.103	0.050
		5.138	

LEU10Mo  
Finish Rolling

3G60-CK-  
PVMF

Loewy Mill

18-May-10

Initial  
Thickness 0.02  
Initial  
Width  
Initial  
Length 37.125

Pass No.	Number of passes	Direction	Mill Setting	Thickness Before	Calculated Thickness After	Length	Measured Thickness After
1	3	R	0.0220	0.0220	0.0197	37.69	
2	3	R	0.0200	0.0197	0.0194	38.19	
3	3	R	0.0180	0.0194	0.0192	38.75	
4	3	R	0.0160	0.0192	0.0187	39.75	0.0177
5	3	R	0.0150	0.0187	0.0182	40.75	0.0171
6	3	R	0.0140	0.0182	0.0177	42.00	
7	3	R	0.0130	0.0177	0.0172	43.25	
8	4	R	0.0120	0.0172	0.0165	44.94	0.0158
9	3	R	0.0120	0.0165	0.0162	45.94	0.0155
10	3	R	0.0115	0.0162	0.0158	46.88	

0.0155

R: Rough texture end first

3G60-CK-PVMF

Final Foil Dimensions

Duncan  
Hammon  
25-May-10

Position	Width	Thick Edge 1	Thick Edge 2	Thick Center
1	2.161	0.0154	0.0154	0.0155
10	2.165	0.0155	0.0155	
20	2.165	0.0156	0.0155	0.0155
30	2.165	0.0156	0.0155	
39	2.158	0.0157	0.0154	0.0154
Average	2.163	0.0155		

Length            39.5

Foil Wt.        332.6

Scrap Wt.       497.9

Gross

Density 15.31209

15.72497

LEU10Mo  
Hot Rolling in a Steel Can

3G60-CN-  
PVNF

Bliss Mill

4/21/2010

Initial  
Thickness 0.414  
Initial Width 4.03  
Initial Length 6.86

Pass No.	Time	Direction	Mill Setting	Thickness Before	Measured Thickness After	Reduction
	9:32					
1	10:15	T	0.400	0.414	0.391	0.023
2	10:20	T	0.380	0.391	0.372	0.019
3	10:25	F	0.360	0.372	0.340	0.032
4	10:30	R	0.320	0.340	0.303	0.037
5	10:35	F	0.280	0.303	0.264	0.039
6	10:40	R	0.250	0.264	0.235	0.029
7	10:45	F	0.220	0.235	0.205	0.030
8	10:50	R	0.190	0.205	0.177	0.028
9	10:55	F	0.165	0.177	0.153	0.024
10	11:00	R	0.140	0.153	0.131	0.022
11	11:05	F	0.120	0.131	0.110	0.021
12	11:10	R	0.100	0.110	0.093	0.017
						31 x 4.7 x 0.081
13	11:15	F	0.090	0.093	0.081	0.012
14	11:20	R	0.080	0.081	0.070	0.011
15	11:25	F	0.070	0.070	0.060	0.010
16	11:30	R	0.070	0.060	0.055	0.005

45 x (4.716/4.721) x (.053/.055)

Air furnace set at 680 C

Anneal 30 minutes after rolling, swap ends at 15 minutes.

Final can dimensions	45	4.716	0.053
		4.721	0.055

Foil dimensions	37	3.015	0.0215
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3G60-CN-  
LEU10Mo  
PVNF  
Finish Rolling                          Loewy Mill                          28-Apr-10

Initial  
Thickness 0.0215

Initial  
Width 3.3

Initial  
Length 36

Pass No.	Number of passes	Direction	Mill Setting	Thickness Before	Calculated Thickness After	Length	Measured Thickness After
1	4	L	0.0215	0.0215	0.0214	36.25	0.0215
2	4	L	0.0200	0.0214	0.0202	38.25	0.019
3	4	L	0.0180	0.0202	0.0194	39.875	
4	2	L	0.0160	0.0194	0.0189	40.875	0.018
5	2	L	0.0140	0.0189	0.0182	42.5	
6	2	L	0.0120	0.0182	0.0173	44.625	0.0165
7	2	L	0.0100	0.0173	0.0164	47.25	0.016
8	2	L	0.0185	0.0164	0.0155	49.875	
9	2	L	0.0085	0.0155	0.0148	52.125	0.015
10	1	L	0.0085	0.0148	0.0146	52.875	0.0145

3G60-CN-PVNF

Final Foil Dimensions

Duncan  
Hammon  
5-May-10

Position	Width	Thick Edge 1	Thick Edge 2	Thick Center
0	2.145	0.0144	0.0140	
8	2.160	0.0144	0.0144	0.0145
16	2.160	0.0144	0.0143	
24	2.161	0.0142	0.0143	0.0145
32	2.156	0.0142	0.0143	
39.5	2.141	0.0145	0.0141	
Average	2.154	0.0143		
12.8	2.161	Notch		
12.8	2.154	Notch		

Length                  39.5

Foil Wt.              307.2

Scrap Wt.             346.8

Gross Density        15.39353

                          15.72339

LEU10Mo

3G60-CK-R1X4

Hot Rolling in a Steel Can

Bliss Mill

27-Jul-10

Initial Thickness 0.409

Initial Width 4.935

Initial Length 6.95

Pass No.	Time	Direction	Mill Setting	Thickness Before	Measured Thickness After	Reduction
	700 C/25 min + 660 C/ 5minutes					
1		F	0.380	0.409	0.368	0.041
2		R	0.340	0.368	0.333	0.035
3	9:53	F	0.300	0.333	0.295	0.038
4	10:00	R	0.260	0.295	0.259	0.036
5	10:06	F	0.230	0.259	0.229	0.030
6		R	0.200	0.229	0.198	0.031
7		F	0.170	0.198	0.168	0.030
8	10:17	R	0.145	0.168	0.147	0.021
9		F	0.120	0.147	0.122	0.025
10		R	0.100	0.122	0.105	0.017
11		F	0.090	0.105	0.094	0.011
12		R	0.080	0.094	0.081	0.013
13	10:35	F	0.070	0.081	0.073	0.008
14		R	0.060	0.073	0.060	0.013
15		F	0.060	0.060	0.055	0.005

In Furnace

4 then 3 minute reheat between passes

52 1/4 x (5.10/5.12) x (.055) cold

10:44 Anneal 30 minutes@660 C, swap ends after 15 minutes

5.120

Final can dimensions	52.250	5.100	0.055
		5.120	

Foil dimensions	41.75	3.860	0.022
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LEU10Mo  
 Finish Rolling      3G60-CK-  
 R1X4      Loewy Mill      29-Jul-10

Initial  
 Thickness      0.024  
 Initial  
 Width      3.86  
 Initial  
 Length      39.75

Pass No.	Number of passes	Direction	Mill Setting	Thickness Before	Calculated Thickness After	Length	Measured Thickness After	Calculated Thickness After Pass 3
1	2	L	0.0230		0.0237	40.25		
2	3	L	0.0210	0.0237	0.0234	40.75		
3	3	L	0.0190	0.0234	0.0230	41.50	0.0195	
4	3	L	0.0170	0.0230	0.0227	42.00		
5	3	L	0.0150	0.0227	0.0221	43.25		
6	3	L	0.0130	0.0221	0.0213	44.75	0.0178	0.0181
7	3	L	0.0120	0.0213	0.0206	46.25	0.0170	0.0175
8	3	L	0.0110	0.0206	0.0202	47.25	0.0165	0.0171
9	3	L	0.0105	0.0202	0.0195	49.00	0.0161	0.0165
10	3	L	0.0105	0.0195	0.0191	50.00	0.0157	0.0162

3G60-CK-R1X4

## Final Foil Dimensions

Duncan

Hammon

4-Aug-10

Position **	Width	Thick Edge 1	Thick Edge 2	
0	2.160	0.0160	0.0162	
9	2.168	0.0159	0.0159	
18	2.163	0.0160	0.0157	
27	2.168	0.0159	0.0158	
36	2.158	0.0160	0.0161	

Length 39.500

Ave. W 2.163

Ave. T 0.0159

Foil Wt. 344.0

Scrap Wt. 446.6

Gross Density 15.42567  
 15.74703 with T= 0.0156

\*\*Note: Position in inches with 18 at the center of the foil.

U235 Fraction (20 % Enrichment and 10 %  
Mo)

	Weight (grams)		U235 Fraction	U235 Weight
Billet	787.4		0.180	141.7
Clad Foil	829.1		0.171	141.7
Zr Cladding	41.7			
Zr Fraction	0.050			
Trimmed Foil	344.0			58.8
Scrap	446.6			76.3
Archive+Met	38.5			6.6

141.7

LEU10Mo

3G60-CN-  
R1X6

Hot Rolling in a Steel Can

Bliss Mill

2-Aug-10

Initial  
Thickness      0.409  
Initial Width    4.01  
Initial Length   6.86

Pass No.	Time	Direction	Mill Setting	Thickness Before	Measured Thickness After	Reduction
	9:35					
1	10:05	F	0.380	0.409	0.369	0.040
2		R	0.340	0.369	0.327	0.042
3		F	0.300	0.327	0.292	0.035
4	10:10	R	0.260	0.292	0.260	0.032
5	10:20	F	0.230	0.260	0.220	0.040
6		R	0.200	0.220	0.194	0.026
7		F	0.170	0.194	0.170	0.024
8	10:23	R	0.145	0.170	0.148	0.022
9	10:33	F	0.120	0.148	0.123	0.025
10		R	0.100	0.123	0.104	0.019
11	10:35	F	0.090	0.104	0.090	0.014
12	10:45	R	0.080	0.090	0.075	0.015
13		F	0.070	0.075	0.065	0.010
14		R	0.065	0.065	0.060	0.005
15	10:48	F	0.065	0.060	0.055	0.005

In Furnace at 660 C

Reheat just to set mill, 10 minutes after pass 4, 8, and 11.

10:50 Anneal 30 minutes@660 C, swap ends after 14 minutes

Final can dimensions	50.500	4.195	0.054
	4.210		0.056

Foil dimensions	41.25	2.970	0.0222
		2.979	0.0229

3G60-CN-  
 LEU10Mo  
 R1X6  
 Finish Rolling                              Loewy Mill                              2-Aug-10

Initial  
 Thickness 0.0223  
 Initial  
 Width 2.974  
 Initial  
 Length 38.75

Pass No.	Number of passes	Direction	Mill Setting	Thickness Before	Calculated Thickness After	Length	Measured Thickness After	Calculated Thickness After Pass 3
1	3	L	0.0210		0.0219	39.50		
2	3	L	0.0190	0.0219	0.0215	40.25		
3	3	L	0.0170	0.0215	0.0209	41.25	0.0192	
4	3	L	0.0150	0.0209	0.0202	42.75		
5	3	L	0.0130	0.0202	0.0194	44.50		
6	3	L	0.0120	0.0194	0.0184	46.88	0.0167	0.0169
7	3	L	0.0110	0.0184	0.0176	49.00		0.0162
8	3	L	0.0110	0.0176	0.0172	50.38	0.0152	0.0157
9	1	L	0.0110	0.0172	0.0169	51.00	0.0153	0.0155

3G60-CN-R1X6

## Final Foil Dimensions

Duncan  
Hammon  
4-Aug-10

Position **	Width	Thick Edge 1	Thick Edge 2	
0	2.165	0.0149	0.0150	
9	2.168	0.0149	0.0150	
18	2.165	0.0150	0.0150	
27	2.169	0.0148	0.0150	
36	2.162	0.0149	0.0150	

Length	39.500
Ave. W	2.166
Ave. T	0.0149
Foil Wt.	327.2
Scrap Wt.	277.6
Gross Density	15.6328
	15.77012      with T=      0.0148

\*\*Note: Position in inches with 18 at the center of the foil.

## U235 Fraction (20 % Enrichment and 10 % Mo)

	Weight (grams)	U235 Fraction	U235 Weight	
Billet	601.2	0.180	108.2	
Clad Foil	632.2	0.171	108.2	
Zr Cladding	31.0			
Zr Fraction	0.049			
Trimmed Foil	327.2		56.0	
Scrap	277.6		47.5	
Archive+Met	27.4		4.7	108.2

LEU10Mo  
 Hot Rolling in a Steel Can  
 Initial Thickness 0.411  
 Initial Width 4.925  
 Initial Length 6.91

3G60-CK-  
R1X9

Bliss Mill

27-Jul-10

Pass No.	Time	Direction	Mill Setting	Thickness Before	Measured Thickness After	Reduction
	700 C/25 min + 660 C/ 5minutes					
1		F	0.380	0.411	0.372	0.039
2		R	0.340	0.372	0.330	0.042
3	2:36	F	0.310	0.330	0.301	0.029
4		R	0.270	0.301	0.266	0.035
5		F	0.230	0.266	0.233	0.033
6		R	0.200	0.233	0.200	0.033
7		F	0.170	0.200	0.172	0.028
8	2:54	R	0.145	0.172	0.148	0.024
9		F	0.120	0.148	0.128	0.020
10		R	0.100	0.128	0.109	0.019
11		F	0.090	0.109	0.095	0.014
12		R	0.080	0.095	0.084	0.011
13	3:12	F	0.070	0.084	0.071	0.013
14		R	0.060	0.071	0.061	0.010
15	3:20	F	0.060	0.061	0.054	0.007

In Furnace

3 minute reheat between passes

50 3/4 x (5.145/5.160) x (.055) cold

Anneal 30 minutes@660 C, swap ends after 15 minutes

5.155

Final can dimensions	50.750	5.160	0.055
		5.145	

Foil dimensions	40.375	3.884	0.023
		3.902	0.0235
		3.889	0.0225

LEU10Mo  
 Finish Rolling      3G60-CK-  
 R1X9      Loewy Mill      29-Jul-10

Initial  
 Thickness      0.023  
 Initial  
 Width      3.9  
 Initial  
 Length      38

Pass No.	Number of passes	Direction	Mill Setting	Thickness Before	Calculated Thickness After	Length	Measured Thickness After	Calculated Thickness After Pass 5
1	3	L	0.0210		0.0226	38.63		
2	3	L	0.0190	0.0226	0.0223	39.25		
3	3	L	0.0170	0.0223	0.0219	40.00		
4	3	L	0.0150	0.0219	0.0213	41.00		
5	3	L	0.0130	0.0213	0.0206	42.50	0.0183	
6	3	L	0.0120	0.0206	0.0199	44.00		0.0177
7	3	L	0.0110	0.0199	0.0191	45.88	0.0172	0.0170
8	3	L	0.0100	0.0191	0.0184	47.50	0.0167	0.0164
9	3	L	0.0100	0.0184	0.0178	49.00	0.0160	0.0159
10	3	L	0.0100	0.0178	0.0173	50.50	0.0155	0.0154

3G60-CK-R1X9

## Final Foil Dimensions

Duncan  
Hammon  
4-Aug-10

Position **	Width	Thick Edge 1	Thick Edge 2
0	2.164	0.0154	0.0157
9	2.168	0.0155	0.0155
18	2.164	0.0155	0.0156
27	2.168	0.0154	0.0155
36	2.160	0.0155	0.0157

Length	39.500
Ave. W	2.165
Ave. T	0.0155
Foil Wt.	336.8
Scrap Wt.	454.4
Gross Density	15.49688
	15.70958      with T=      0.0153

\*\*Note: Position in inches with 18 at the center of the foil.

U235 Fraction (20 % Enrichment and 10 % Mo)

	Weight (grams)	U235 Fraction	U235 Weight
Billet	792.1	0.180	142.6
Clad Foil	834.6	0.171	142.6
Zr Cladding	42.5		
Zr Fraction	0.051		
Trimmed Foil	336.8		57.5
Scrap	454.5		77.6
Archive+Met	43.3		7.4

142.6

## Starting Dimensions of LEU10Mo Billets (R1X)

	SAMPLE R1X8	SMALL R1X6	LARGE R1X4	LARGE R1X9
Width 1	1.947	2.852	3.76	3.75
Width 2	1.946	2.852	3.761	3.75
Width 3	1.946	2.852	3.764	3.748
<b>Avg Width</b>	<b>1.946</b>	<b>2.852</b>	<b>3.762</b>	<b>3.749</b>
<b>SD of Width</b>	<b>5.774E-04</b>	<b>0.000E+00</b>	<b>2.082E-03</b>	<b>1.155E-03</b>
Length 1	2.875	5.751	5.753	5.752
Length 2	2.875	5.75	5.755	5.749
Length 3	2.875	5.751	5.754	5.749
<b>Avg Length</b>	<b>2.875</b>	<b>5.751</b>	<b>5.754</b>	<b>5.750</b>
<b>SD of Length</b>	<b>0.00E+00</b>	<b>5.77E-04</b>	<b>1.00E-03</b>	<b>1.73E-03</b>
Thickness 1	0.13	0.13	0.131	0.131
Thickness 2	0.131	0.1305	0.131	0.131
Thickness 3	0.1315	0.13	0.131	0.1305
Thickness 4	0.13	0.1315	0.131	0.131
Thickness 5	0.13	0.1315	0.1315	0.131
Thickness 6	0.13	0.1315	0.131	0.131
Thickness 7	0.1315	0.1295	0.1295	0.13
Thickness 8	0.1315	0.1295	0.1295	0.13
Thickness 9	0.1315	0.13	0.13	0.13
<b>Avg Thick</b>	<b>0.131</b>	<b>0.130</b>	<b>0.131</b>	<b>0.131</b>
<b>SD of Thick</b>	<b>7.55E-04</b>	<b>8.46E-04</b>	<b>7.41E-04</b>	<b>4.86E-04</b>
Surface Finish	40	51	60	50